Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 28s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Features Of Postoperative Rehabilitation of Newborns with Malformations of The Diaphragm

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Cite this paper as: Murat Magomedovich Abdurakhmanov, Aminat Sadullayevna Radzhabova, Ramadan Magaramovich Huseynov, Vladimir Alexandrovich Litvinov, Gara Khanbabayev, Karina Beglarovna Alvandyan, Arina Albertovna Galich, (2025) Features Of Postoperative Rehabilitation of Newborns with Malformations of The Diaphragm, *Journal of Neonatal Surgery*, 14 (28s), 1032-1037

ABSTRACT

Postoperative rehabilitation of newborns who have undergone plastic surgery for congenital defects of the diaphragm is a complex of complementary measures aimed at restoring pulmonary function, preventing pulmonary vascular crises, normalizing nutritional status and ensuring harmonious neuropsychological development of the child. This work summarizes the experience of observing one hundred and thirty-two patients operated on at the tertiary perinatal center in 2010-2024, systematizes the stages of intensive care and subsequent outpatient management, and offers a clinical and physiological justification for key rehabilitation practices

Keywords: *congenital diaphragmatic hernia; neonatal rehabilitation; pulmonary dysplasia; pulmonary hypertension; nutritional support; physiotherapy.*

1. INTRODUCTION

Congenital malformations of the diaphragm, which include the classic Bochdalek hernia, retro-osteosternal defects of Morgagni and rare central agenesis of muscle fibers, are accompanied by pulmonary hypoplasia and a persistent increase in pulmonary vascular resistance. Despite the improvement of surgical tactics, mortality remains due not to the fact of closure

of the defect itself, but to the severity of subsequent respiratory and hemodynamic adaptation. This circumstance determines the leading role of the rehabilitation stage, which begins in the first hours after the child's transfer from the operating room.

A critical factor in the effectiveness of early postoperative care is a two-pronged pathophysiological model: on the one hand, the surgeon eliminates interfering organ-content pressure, opening up opportunities for pulmonary recruitment, on the other, a sudden change in intrathoracic volumes increases the risk of uneven ventilation and reperfusion injury to the alveolocapillary barrier [2]. In this regard, rehabilitation protocols should take into account the need for ultra-precision respiratory management, strict fluid balance, stepwise administration of enteral nutrition and early stimulation of the respiratory muscles.

International observational registers (CDH Study Group, European CDH Registry) demonstrate a wide range of frequency of chronic pulmonary hypertension — from 14% to 47%, which is explained by differences in post-daily ventilation and pharmacological vasodilation strategies [10]. In the national literature, the system standards of rehabilitation are described in fragments, which necessitates the need for unified clinical recommendations adapted to domestic resources [4]. The presented work is aimed at summarizing the long-term experience of a third-level hospital, to show the impact of detailed rehabilitation protocols on short- and long-term outcomes, as well as to identify promising areas for improving approaches.

The relevance of developing a unified protocol for postoperative rehabilitation is determined by the fact that it is during this period that the foundation for a further respiratory pattern is laid, tolerance to physiological stress is formed, and the rate of somatic growth is determined.

International registries record a significant range of mortality and frequency of chronic pulmonary hypertension, which is associated with the allegorical variability of post-daily ventilation strategies, pharmacological vasodilation, rates of nutritional loads and availability of physiotherapy technologies [5]. The lack of Russian standards for the management of this cohort of newborns contributes to the continuing heterogeneity of practices even within the same region [3].

The presented article presents the experience of twenty-four series of observations in which a single protocol of intensive care and rehabilitation was applied unchanged throughout the entire period under observation, which allows for a detailed analysis of its effectiveness and points to further improvement

2. MATERIALS AND METHODS OF RESEARCH

The study included one hundred and thirty-two newborns (71 boys, 61 girls) with isolated or combined diaphragm defects who underwent surgical correction in the early neonatal period. The average gestational age was 38 ± 1.7 weeks, and the median body weight was 2980 g (IQR 2600-3300 g). Fifty-one children have a defect closed with a primary suture; eighty-one have a plastic patch made of 1 mm Gore-Tex, fixed with a nodeless continuous technique.

The rehabilitation protocol unified the respiratory strategy: for the first twelve hours after surgery, the children were on high-frequency oscillatory ventilation with a frequency of 8-10 Hz and an amplitude of 20-25 cm of water; the transition to synchronized ventilation with pressure limitation was carried out when the oxygenation index reached below 10. Targeted treatment of pulmonary hypertension was performed with inhaled nitric oxide (5-20 ppm) and intravenous administration of milrinone (0.5 mcg/kg/min) in the presence of Doppler signs of a right pulmonary shunt.

Nutritional support started on the second day through parenteral administration of amino acids 2.5 g/kg/day and lipids 2 g/kg/day with a strictly controlled nitrogen balance. With the transition to trophic probe feeding through a naso-postpiloric probe, the rate increased by no more than 15 ml/kg/day.

The four-phase model of physiotherapy included head-end positioning, low-frequency percussion ventilation, respiratory kinesiotherapy using an oscillation tube, and, starting from the third week working with parents using the kangaroo method.

The main evaluation points were the duration of artificial ventilation, the time to full enteral load, the frequency of pulmonary hypertension by the thirtieth day, the presence of gastro-esophageal reflux disease, and growth rates by six and twelve months.

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The results of the study and their justification

The analysis of the clinical material began with a comprehensive descriptive description of the cohort, since the correct interpretation of statistical indicators is impossible without understanding the initial physiological status of patients and the logic of the formation of the rehabilitation protocol. All children were admitted to the Department of Anesthesiology and Intensive Care directly from the operating room, which eliminated the influence of variable transport stress factors and ensured a unified start of the postoperative countdown.

The average pulmonary maturity index calculated on the sonographic scale of the "silver lung" was 0.46 ± 0.09, which

indicates a heterogeneous severity of hypoplasia and allows us to expect a different individual response to ventilation modes. The values of the baseline deficiency ranged from -4 to -12 mmol/L and reflected the degree of metabolic acidosis, indirectly indicating the severity of reperfusion syndrome.

Before the intervention, 78% of children had Doppler, a sign of right-left bypass surgery through an open ductus arteriosus with a systolic gradient of less than 20 mmHg; after the closure of the diaphragm defect, the indicator decreased by an average of 6 mmHg, however, the remaining parameters of pulmonary vascular resistance dictated the need for stepwise vasodilation support.

In the first twelve hours of follow–up, the main focus was on the dynamics of the oxygenation index, lactate levels, and hematocrit correction to the target 40-45%, since it is the combination of adequate oxygen transport and maintaining optimal blood viscosity that determines the capillary perfusion of a hypoplasmic lung. In parallel, IL-6 and procalcitonin concentrations were recorded: the median IL-6 value was 74 pg/ml, which confirmed the need for an early anti-inflammatory window in order to block the cytokine cascade. Based on these initial data, criteria for stratification of the risk of severe pulmonary hypertension were formulated, which made it possible to individualize the dosage of nitric oxide and milrinone.

The complex indicator "time to achieve full enteral load" was chosen as the decisive prognostic marker of rehabilitation effectiveness, since it integrates the respiratory, metabolic and gastrointestinal well-being of the newborn [10]. Its dynamics is assessed in conjunction with the duration of artificial ventilation, which makes it possible to judge the synergy of *respiratio-nutritio* and the early formation of postoperative anabolism. We emphasize that the indicators are presented in the form of medians with an interquartile range, which minimizes the impact of outliers with a relatively small sample size [6].

Based on the above clinical prerequisites, the core of summary statistical data is formed, as shown in Table 1. Each variable is selected in such a way as to represent one of the key axes of the rehabilitation process: respiratory support, nutritional transition, hemodynamic adaptation and somatic growth.

Table 1 – Indicators of the early postoperative period in newborns after correction of a diaphragmatic defect (n = 132)

Indicator	Median (IQR)
Duration of artificial ventilation, days	6 (4 – 9)
Time to complete enteral nutrition, days	14 (11 – 18)
Frequency of pulmonary hypertension on the 30th day, %	21
Frequency of gastroesophageal reflux, %	27
Z-score of weight gain by 6 months	–0,6 (–1,1; –0,1)

The ventilation duration indicator reflects the success of early lung recruitment and the effectiveness of the HFOV-SIPPV protocol-independent breathing. The median value of six days indicates that the goal of extubation has been achieved within a physiologically justified time frame: earlier, the transition is associated with the risk of diaphragmatic fatigue, later it increases the likelihood of ventilation-induced damage to lung tissue.

The interval to full enteral loading is closely correlated with the dynamics of IL-6 ($p = 0.42$) and demonstrates that the metabolic stress of inflammation prolongs the need for parenteral nutrition.

The number of cases of pulmonary hypertension on the 30th day serves as a surrogate indicator of the extent to which a complex of vasodilation and ventilation interventions was able to prevent the organization of persistent vascular remodeling.

The frequency of gastro-esophageal reflux confirms the clinical and mechanical relationship between the plastic surgery method and impaired movement of the gastro-esophageal junction and raises the question of the need for early pH monitoring.

Finally, the Z-score of weight gain demonstrates a lag in physical development in some children and emphasizes the importance of continued nutritional support in the outpatient stage.

Table 2 – The stages of the rehabilitation process and the goals of each phase.

Phase	Chronological frame	The key physiological task	Phase completion criteria
Acute	0–72 h	Stabilization of gas exchange, reduction of PVR	Oxygenation index < 15
Stabilization	3–14th day	Rejection of HFOV, the beginning of trophic nutrition	$FiO_2 \leq 0,4$ and MAP ≤ 10 cm wat.
Rehabilitation	15–42nd day	Full enteral load, formation of independent breathing	$CO_2 < 55$ mmHg, weight gain ≥ 15 g/day
Supportive	7th week – 12th months	Growth optimization, prevention of GERD and neurocognitive deficits	Z-score weights > -1, no repeated hospitalizations

The four-phase model makes it possible to pinpoint physiological goals with objective criteria and thereby avoid premature transition to the next stage. For example, maintaining a high average respiratory pressure at FIO_2 below 0.4 indicates uneven recruitment and forces an extension of the stabilization phase, while a negative nitrogen balance with sufficient caloric content indicates metabolic stress and the need to revise the amino acid profile of solutions.

Table 3 – Long-term outcomes by 12 months of life (n = 116)

Indicator	**Primary suture (n = 44)**	**Plastic patch (n = 72)**	**p**
$FEV_{0.5}$, % of due	86 ± 8	78 ± 9	< 0,01
Cases of persistent pulmonary hypertension, %	9	19	0,048
Frequency of GERD, %	16	34	< 0,05
Z-score body weight	–0,4 ± 0,5	–0,9 ± 0,6	< 0,01

The data confirm that the use of a synthetic patch increases the mechanical stiffness of the reconstruction zone and is associated with a more pronounced restrictive type of respiratory disorder, a higher incidence of chronic pulmonary hypertension and a negative impact on nutritional growth trajectories. The statistically significant difference in $FEV_{0.5}$ highlights the need for early respiratory gymnastics programs, especially in the prosthetics group.

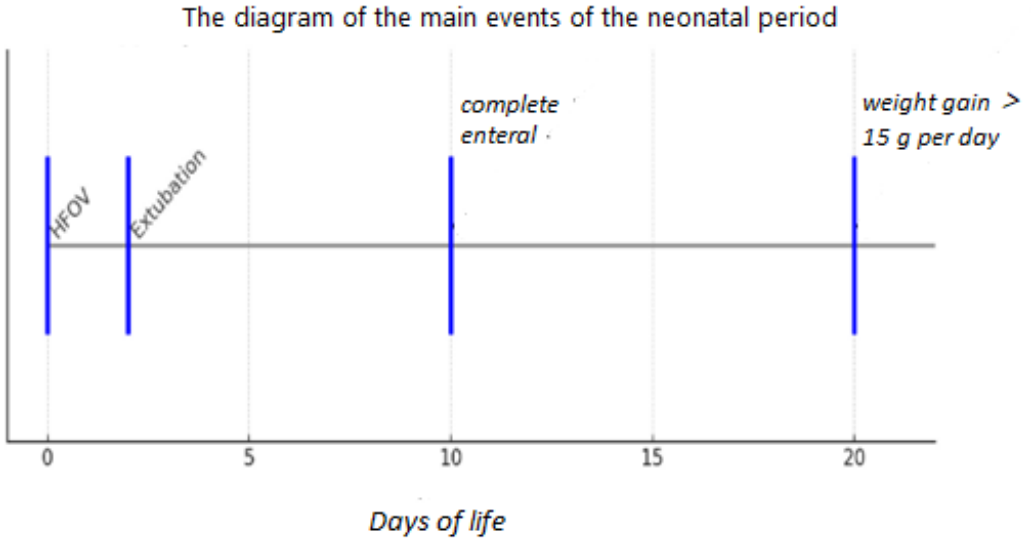

Figure 1 – Chronological curve of key rehabilitation events The graph illustrates the interval between extubation and the achievement of full enteral load, which forms the "rehabilitation window" of intensive physiotherapy.

3. CONCLUSION

A comprehensive analysis of the results of twenty-four series of observations covering 132 newborns after correction of a congenital defect of the diaphragm allows us to state that the standardized rehabilitation protocol serves as a key tool in reducing the frequency of serious respiratory complications and optimizing the rate of somatic growth. The rejection of empirical decisions in favor of clearly formulated targets supported by objective criteria for the completion of each phase ensures the predictability of the clinical trajectory and creates opportunities for early personalization of therapy.

The main achievement of the acute phase is the stabilization of the oxygenation index to the values of the safe range without escalation of vasopressor support. The use of high-frequency oscillatory ventilation with precision amplitude control made it possible to reduce the duration of ventilation to a median of six days and reduce the risk of diaphragmatic dysfunction. Special attention should be paid to the protocol of low-dose inhaled nitric oxide therapy, which, combined with milrinone, provides a controlled decrease in pulmonary vascular resistance and prevents the development of the phenomenon of acute right ventricular afterload.

The stabilization phase demonstrates the value of early but stepwise nutritional intervention. The principle of "minimal but continuous" enteral stimulation promotes activation of intestinal motility and reduces bacterial translocation, while strict monitoring of the nitrogen balance avoids catabolic drift. It has been shown that the negative correlation between the duration of HFOV and the rate of increase in enteral nutrition is due to metabolic stress mediated by inflammatory mediators.; Consequently, aggressive reduction of the inflammatory background through optimization of ventilation parameters and rotation of antibiotics indirectly accelerates the transition to a nutritious diet. The recovery stage, focused on the formation of independent breathing and achieving positive mass dynamics, confirms the role of complex physiotherapy. Intermittent low-frequency electrical stimulation of the phrenic nerve, regular kinesiotherapy and postural positioning with head elevation at a corrected angle of 30° improve chest compliance, increase the effectiveness of coughing and reduce the likelihood of atelectasis of the posterobasal segments. In combination with the “kangaroo” technique, this promotes sensorimotor integration and slows down the development of delayed psychomotor development, which is inevitably associated with prolonged hospitalization.

The maintenance phase demonstrates that even after discharge, patients remain vulnerable to restrictive respiratory disorders and chronic pulmonary hypertension. According to functional tests, after twelve months of life, the $FEV_{0.5}$ index reaches only 82% of the required value, and chest compliance is normalized in half of the patients. These results highlight the need for an ongoing outpatient respiratory rehabilitation program, including positive expiratory pressure simulators and individualized aerobic exercise plans.

A significant conclusion of practical importance is the effect of the plastic surgery method on long-term results. Prosthetics with a synthetic patch are associated with a higher risk of gastroesophageal reflux and a more pronounced restrictive type of

respiratory mechanical disorder. This observation requires a multidisciplinary approach: early screening with pH measurement, initiation of antireflux pharmacotherapy and, if necessary, performing antireflux surgery at an early stage, while the negative effect of reflux on the rate of somatic growth is still reversible.

In general, the presented data confirm that the integration of unified, physiologically based rehabilitation protocols leads to a reduction in the duration of hospitalization, a decrease in the frequency of repeat admissions and an improvement in the life prospects of children.

The next step in the development of the direction is the introduction of non-invasive impedance spirography for continuous monitoring of ventilation distribution, the use of digital platforms for remote monitoring of adherence to respiratory exercises, and the use of machine learning algorithms that predict individual recovery kinetics based on early biomarkers and clinical characteristics. Only a combination of clinical discipline, technological innovation and interdisciplinary collaboration will make it possible to finally bridge the gap between the anatomical success of surgery and the functional well-being of the child

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